EXPLOSIVES DEPARTMENT

HERCULES POWDER COMPANY

INCORPORATED

HERCULES TOWER · 910 MARKET STREET · WILMINGTON 99, DELAWARE

August 30, 1962

Uranium
GD/FW

General Dynamics Corporation
P. O. Box 748
Fort Worth 1, Texas

Attention: L. H. Schreiber
Chief of Propulsion

Subject: Cost Estimate for Minuteman XM-57 and Polaris A-2 Rocket Motors

Reference: Letter from General Dynamics, Gen. FW #6-2619, dated July 31, 1962

Dear Sir:

In response to your request for a delivery and cost estimate for furnishing sixteen motors, either XM-57, A-2 or A-3, the following estimate is submitted.

(1) The environmental requirements data requested is enclosed but is limited to those data of an unclassified nature. Because General Dynamics' "need to know" has not been established with Ballistic Systems Division, AFSC, California, data of a classified nature cannot be furnished. In the event such classified data is required, Hercules will be happy to assist in establishing a "need to know" and, if necessary, furnish technical representation to discuss this aspect verbally.

(2) Delivery of the first Minuteman M-57 motor could be made thirty-two (32) weeks after receipt of General Dynamics' purchase order or other contractual document. The remaining 15 motors could be delivered at the rate of one (1) per week thereafter. Delivery of the first A2P motor could be made thirty-three (33) weeks after receipt of General Dynamics' purchase order or other contractual document. The remaining 15 motors could be delivered at the rate of four (4) per month thereafter.

(3) The motors can be furnished at an estimated cost as follows:

XM-57 Motors	$155,281.00 per motor
A2P Motors	$164,536.00 per motor

(4) The above unit prices and deliveries are based upon the following conditions:

a. F.O.B. point will be Bacchus, Utah

b. Motors furnished will be of current design configuration in effect at the time of receipt of order, and modifications or engineering changes to be applied subsequently will be priced separately and in addition to unit prices quoted.

c. Furnishing of technical assistance or representation sustaining engineering, design engineering or development effort are not included in the unit prices quoted.

d. Prices quoted do not include the cost of furnishing the following:

1. Ground support equipment necessary for operation of motors.

2. Additional motors required for Quality Assurance firings and destructive testing. The Air Force currently requires, under a given ratio, that for each set quantity of motors produced a designated quantity of motors will be provided for Quality Assurance and destructive testing in order to maintain reliability.

3. Costs and/or furnishing of harness assembly, motor transporter or other equipment necessary in the transporting and handling of the motor. Available equipment of this nature presently is Air Force property and is in critical short supply.

4. Any contractual document resulting from this estimate shall include authorization for Hercules Powder Company to use on a rent-free, non-interference basis any Government property and/or facilities in its possession under Facilities Contracts AF 04(647)-535, AF 04(647)-722, NOw-61-06474, NOw-6105 and NOw-61-0160u; also appropriate authorization for use of Government-owned special tooling acquired under Contracts AF 04(647)-690, AF 04(647)-243, AF 04(694)-127, LMSC 18-02223, 18-1020040, 18-02221, 18-102006, NOw-61-0149C, and NOw 62-0504c.

5. Costs for subsequent interstaging and interfacing requirements that may be required to integrate the motors into another system.

6. The cost of Government-furnished components and/or material presently being used in these motors and furnished to Hercules Powder Company without cost. The availability of these items from the Air Force and the Navy cannot be determined at this time and necessitates prices as quoted above becoming contingent upon the Government supplying these items without cost. Some examples, but not a complete listing, of these items are: Base grain propellant, mounting brackets, actuator linking arms, hydraulic packages, safe and arm device, etc.

7. The Thrust Vector Control System is not included. An additional cost will be adde if the motors procured contain this control system.

8. Static testing, test equipment, gages, and other miscellaneous items necessary for testing and environmental control during transporting and handling of the motors after receipt by General Dynamics are not included in these costs.

Prices and deliveries as quoted are "ballpark" estimates submitted for planning purposes, and time did not permit research of details which may, when completed, eliminate some of the applied contingencies. In the event the information as furnished is not adequate for your needs, or a refinement into a more detailed and firm proposal is required, please advise and prompt action will be taken to supplement this estimate accordingly.

Very truly yours,

A. F. Giacco

A. F. Giacco
Director of Sales Development
Chemical Propulsion Division

AFG - BB:tmw

Enclosure

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ENVIRONMENTAL TEST RESULTS FOR THE M-57 AND A2P MOTORS

The environmental factors included in your inquiry have been investigated. It appears that none of them will prove critical in eliminating either the M-57 or the A2P motor from consideration. Some testing is indicated to verify certain points where safety factors may be too small.

Temperature cycling tests are currently being extended to greater temperature extremes on the M-57 motor in connection with a present program. Test results will materially reduce the number of temperature gradient tests required to demonstrate motor capability in this regard.

The acoustic environment is expected to present no problems, since the levels to which the motors will be exposed have been substantially exceeded.

Vibrational test data from the M-57 engine indicate that expected levels have been exceeded in previous tests. The A2P motor has not been thoroughly tested in this area.

Experimental bending moment and stress data when compared with the expected application indicate that either motor will perform satisfactorily.

These stress points have been analyzed for both the M-57 and the A2P motors. In most cases a substantial safety factor was found to exist. The data are summarized:

Stress Point	Bending Moment by Test (minimum)	Equivalent Stress	Moment (from diagram)	Safety Factor
M-57 aft Y-joint	0.925×10^6 in-lb	12,315 psi	0.62×10^6	1.49 (moment)
	1.0×10^6	11,270		2.51 (stress)
M-57 aft skirt	Not Critical			6.0 (stress)
A2P aft skirt	0.575×10^6	17,000		3.8 (stress)
	0.665×10^6	Negligible	0.62×10^6	1.07 (moment)
A2P forward skirt	0.310×10^6	Negligible	0.25×10^6	1.25 (moment)
	0.225×10^6	4,500	0.25×10^6	4.0 (Shear)

Since the mode of structural loading in these tests was combined axial and moment, it may be assumed that both motors would have a higher bending moment capacity than is indicated here. The above loads are limit loads under launch and flight conditions. Effects of these loads applied for extended time periods is not known.

I EFFECTS OF PRE-LAUNCH ENVIRONMENTAL TEMPERATURES

Imposing a temperature gradient upon either the M-57 or the A2P motor prior to firing the unit, as described in Figures 1 through 12 of your Request, will probably have no effect upon ignition or operation of the motors. Logistic test data on both units indicate satisfactory storage at +30° to +120°F. Cycling has been performed between these limits with no effect on either motor performance or reliability. Tests are presently being made to extend these temperature limits. Such tests would be necessary in order to confirm the usefulness of these motors for the indicated application, or before we could predict with any degree of certainty within what temperature limits the motors could be reliably operated.

The temperature gradient can be reduced somewhat if cork is substituted for Avcoat as the external aerodynamic insulation. This is standard practice at the present time for the M-57 motor. Cork-insulated SPIRALLOY can withstand extremes of temperature (-65° to 150°F) and low pressures (30,000 ft altitude) for at least several hours without damage to either the cork or the adhesive bond. Cork is a more efficient insulator than is Avcoat either on an equal-thickness basis, and still better on an equal-weight basis.

II ACOUSTIC NOISE ENVIRONMENT

The sound pressure levels experienced by the M-57 motor exceed 170 db during silo launch. While this intensity occurs only for a few seconds, it is reasonable to assume that the acoustic intensities indicated will not affect operation of the M-57 motor when applied for the approximately 55 second period of duration. No similar data have been made available to Hercules for the A2P motor. Again, because of the similarities between it and the M-57 motor, no deleterious effect is anticipated from the acoustic field.

III BENDING MOMENT AND SHEAR LOADING DATA

The bending moment continually decreases from the front suspension hook forward. The probable points of maximum stress are:

1. Aft portion of aft akirt (aft interstage attachment flange) where maximum bending moment occurs.

2. Aft Y-joint (attachment of skirt to pressure vessel) where minimum section modulus occurs.

3. Forward skirt (less structural strength is required here than in the aft skirt in present motor utilization).

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IV VIBRATION ENVIRONMENT

Vibration testing to date indicates that no structural problems or difficulties are anticipated with the M-57 motor in this area. Requirements for the A2P motor have not been as severe, hence testing has not been as rigorous, and has not exceeded General Dynamics requirements. In view of the similarity of construction of the two motors, however, it seems reasonable to assume that the A2P mtor also might be expected to qualify. Present handling and stowage design requirements for the A2P motor are that it must withstand MIL-Std-167 Type I criteria.

A summary of vibration testing and test results on the M-57 motor is given below.

Test 1 - 5000 Mile Road Test

This motor was transported in a horizontal position, therefore, inputs were vertical (transverse) and longitudinal having very little side motion. Frequencies were generally below 30 cps.

Vertical Cycles	Longitudinal Cycles	Acceleration Level
1	0	2 g's
100	10	1 g's
3000	5000	1/2 g
1,000,000	50,000	1/4 g

Test 2 - High Load Road Test at Aberdeen Proving Grounds

The response of the motor was measured while being transported over a 2" sinusoidal course, a Belgian block course and a 3" spaced bump course. Frequencies were generally below 30 cps.

Vertical Cycles	Acceleration Level
20	3 g's
700	2-1/2 g's
2,000	2 g's
20,000	1 g
20,000	1/2 g
7,000	1/4 g

Test 3 - Vibration Survey of a Minuteman Stage III Motor

This motor was suspended horizontally by use of air springs. Vertical inputs were applied through drive rings at the motor's tangent lines. Longitudinal (axial) inputs were applied through a drive cone attached to the forward skirt.

During the frequency response portion of the test vertical (transverse) and axial accelerations were seen by the motor as follows:

Frequency (cps)	Acceleration Level (g's)	No. of Cycles	Axis
5 to 500	2 to 3	1×10^6	Vertical
5 to 500	1 to 2	3×10^6	Vertical
5 to 300	1 to 2	1×10^6	Axial

A fatigue type test with axial inputs applied to the forward skirt through a drive cone was also performed:

Frequency (cps)	Acceleration Level (g's)	No. of Cycles	Axis
45	3*	8.59×10^6	Axial

* An acceleration level of 3 g's was held on the forward dome of the motor. This level was amplified to 3.65 g's on the aft end of the motor.

Test 4 - Vibration Testing of a Minuteman Stage III Inert Motor

The motor was suspended vertically by cables attached to the forward skirt. Input was applied at various points on the cylindrical portion of the motor by use of 100 square inch vacuum-attached drive pads. The input was controlled by use of load cells and generally held at 1000 pounds force.

The test series consisted of logarithmic frequency sweeps from as low as 5 cps to as high as 2000 cps and steady state vibration dwells where surveys were made for motor resonances and mode shapes. An estimate of 21×10^6 cycles were applied to the motor, the major portion during steady state dwells at frequencies between 80 and 200 cps. Figure 1 shows acceleration of the motor adjacent to the drive pad as a function of frequency. It must be noted, however, that the entire motor did not see this level. For example, at 520 cps an acceleration level of 6 g's was seen near the input while only 0.2 g's was transmitted to the opposite side of the motor.

Several impact type loads were also applied to the motor where vacuum in the drive pad was lost.

X-ray of the motor after testing revealed no damage due to testing.